ENVIRONMENTAL CONTROL UNIT
FOR
DAMAGE CONTROL SUIT SYSTEM

DEPARTMENT OF THE NAVY
SUPPLY SYSTEMS COMMAND

NAVY CLOTHING AND TEXTILE RESEARCH UNIT
NATICK, MASSACHUSETTS

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George M. Orner and Norman F. Audet

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13. ABSTRACT

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This ECU uses wet ice in finned canisters for cooling purposes, Closed circuit, forced ventilation is effected with a battery powered fan. An easily replaceable chemical pack containing lithium hydroxide and potassium superoxide provides for carbon dioxide removal and replenishment of oxygen. The system will support a man for 1 hour at an ambient temperature of 100°F while performing moderate to heavy activity and at 140°F performing light activity and for 2 hrs while performing light activity in ambient temperatures of 100°F.

A highly efficient oxygen-sensing warning device constantly monitors oxygen level within the suit. Currently, the ECU is worn as a backpack, but contemplated modifications to a torso styled pack would facilitate entry through the small hatches and passageways found aboard ship. (U)

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by

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ABSTRACT

The Navy Clothing and Textile Research Unit (NCTRU) has developed an Environmental Control Unit (ECU) for a life support system which was designed primarily for shipboard operations, such as damage control, rescue, and engine-room use, particularly during shutdown periods. The purpose of the ECU is to control the environment within a fully enclosed, impermeable Damage Control Suit (DCS).

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ENVIRONMENTAL CONTROL UNIT FOR DAMAGE CONTROL SUIT SYSTEM

INTRODUCTION

The Navy Clothing and Textile Research Unit (NCTRU) is developing a life-support system, which consists of a fully enclosed, impermeable suit and an Environmental Control Unit (ECU) for maintaining a habitacle environment within the suit that can support a man for periods up to two hours depending upon the ambient temperature and work activity regimen.

The current NCTRU interest is in developing a life support system primarily for shipboard use in which many situations exist requiring protection of this kind. For example, engine-room environments are often severe, particularly during shutdown periods. Temperatures as high as 140°F are frequently encountered which, when coupled with high humidity, preclude the entry of engine-room personnel, even to perform such light duties as watchstanding for reasonable periods without being subject to severe heat stress. Other shipboard uses for the life-support system include damage control and rescue operations in which personnel may be required to enter spaces filled with smoke or toxic gases.

The purpose of the ECU, which uses wet ice for a coolant, is to control the environment within a fully enclosed, impermeable suit (Damage Control Suit, or DCS), which is also being developed at the NCTRU's Laboratory. The ECU is designed to circulate and cool the air within the suit, remove excess moisture and carbon dioxide, and maintain a safe oxygen level, thus providing maximum personnel protection against hostile environment , such as toxic gases, low-oxygen levels, high humidities, and temperature extremes.

Although additional work is required on this unit and modifications are being considered, it appears that the system is well able to fulfill its intended objectives. Tests have shown that a man can be maintained for periods up to 120 minutes in 100°F environments while performing light activity and for 60 minutes at 140°F at light activity. Moderate to heavy activity can be performed for 60 minutes at temperatures up to 100°F.

The main modification contemplated at this time is a redesign of the ECU into a torso shaped pack. This change would provide a configuration which would facilitate entry through the small hatches and passageways found aboard ship. This new design would also allow the pack to be worn outside the suit and interface with the suit by special connectors. This interface would permit the exchange of the ECU without leaving the work area, thus increasing work duration if necessary.

In this report the design and performance of the ECU are discussed. Data are presented showing the rate of heat absorption under a wide variety of inlet-air-temperature and relative-humidity conditions.

DESCRIPTION OF ECU

There are three basic requirements for the support of a man in a fully enclosed space: temperature control, oxygen supply and the removal of carbon dioxide. In the NCTRU DCS, as with most life-support systems, metabolic heat is dissipated from the man's body by evaporation and convection into the air within the suit, which must be continually cooled and dried. Several methods for cooling the air have been tried.

Previous work at NCTRU includes the development and testing of a fan-ventilated suit (1), an insulated impermeable suit supplied with compressed air for ventilation, cooling and breathing purposes (2), the evaluation of a thermoelectrically cooled suit (3), and the physiological evaluation of a liquid-air suit (4). It was shown that, when compressed air is used, the tolerance time for personnel under elevated temperature conditions can be appreciably extended. The thermoelectric approach was unsatisfactory because of the weight and bulk of thermoelectric devices available at that time. The liquid-air approach, attractive because the liquid air provides cooling, air for breathing and power for its own circulation, is not generally suitable for shipboard use because liquid air is not usually available aboard ships. Although each approach has its own advantages and disadvantages, the wet-ice method appears to be the most suitable for shipboard use. Wet ice is easily produced and is a desirable refrigerant material. It is safe, non-toxic and, pound-for-pound, absorbs as much heat as liquid air (between 0° and 70°F for ice and -314° and 70°F for air).

The ice for the NCTRU ECU is contained in two finned canisters, each of which holds six pounds of ice. Fins formed from deeply corrugated aluminum sheeting are brazed to the four vertical sides of the canisters, as illustrated in Figure 1, which shows the assembled ECU and its component parts.

The ECU, which measures approximately 28" x 14" x 8", weighs about 40 pounds when fully loaded with ice and chemical packs. Its case and the freeze canisters were made by the Frigivest Company under contract to NCTRU. The case is constructed of PVC plastic with a double outer wall sandwiching 3/8-inch-thick polyurethane foam for insulation. The upper section of the ECU comprises the plenum, which is sound-foam lined and which contains the blower. The compartment for the chemical pack lies directly below the plenum. It attaches to the lower section of the ECU with quick-release fasteners to expedite relacement of the freeze canisters. A tank is provided below the freeze-canister compartment to contain the condensate. Check valves prevent the condensate from flowing back into the freeze-canister compartment should the ECU become inverted. The ECU is designed so that both the cooling canisters and the chemical pack can be quickly and readily replaced when the DCS is being used on an extended mission.

The ECU is worn inside a pouch, which is attached to the upper back of the DCS (Figure 2). An aluminum frame strapped to the wearer supports the backpack and the polycarbonate plastic dome helmet. The frame, illustrated in Figure 3, is equipped with padded straps which pass over the wearer's shoulders. It attaches also to the hips by means of a pad riding in the small of the back and a strap encircling the waist. Thus, weight is evenly distributed over the wearer's body. Two, adjustable, aluminum supports are fixed to the frame and to the neck ring of the DCS to support the dome helmet.

Figure 4 presents a schematic illustration of the backpack. Air enters through the inlet, located at the lower end of the freeze canisters, and passes upward through the canister fins, giving off heat and moisture as it cools. Passing through the chemical canister, the air gives off additional moisture, oxygen is produced and carbon dioxide is removed. The chemical canister measures 10" x 5-5/8" x 3-1/2". It weighs 4-3/4 pounds when filled with lithium hydroxide, for the removal of carbon dioxide, and potassium superoxide, for the replenishment of the oxygen. The canister bodies are made of stainless steel sheet and contain twelve 3-1/2" deep troughs, made from metal screening running along the length of the canister. The troughs hold the coarsely granular chemicals in layers to allow a free, well-distributed flow of air through the pack. Seven troughs are filled with potassium superoxide for the production of oxygen according to the equation

$$2KO_2 + H_2O \rightarrow 2KOH + 3/2\ O_2 + \text{Heat}$$

The remaining five troughs are filled with lithium hydroxide for the removal of carbon dioxide according to this equation

$$2\ LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O + \text{Heat}$$

Since the moisture in the air greatly exceeds that required for the production of oxygen, a perforated baffle, which diverts most of the air through the lithium hydroxide, is placed over the side of the chemical pack that contains the potassium superoxide. A sodium chlorate candle, which is incorporated within the chemical pack for emergency use, is fired electrically and produces enough oxygen to support a man for 10 minutes. The development, construction and testing of the chemical canisters were done by the MSA Corporation under contract to NCTRU (5). Concurrently with the development of the chemical pack, an alternate oxygen-supply system using high-pressure oxygen was developed. This system contains oxygen contained in a 54 cubic-inch 301 stainless steel bottle made by the Ardé Company using standard roll and weld techniques. After fabrication, however, a special technique is used to strengthen the bottles by stretching them at cryogenic temperatures. The low-temperature deformation converts the very ductile, but low-strength, austenitic 301 stainless steel to the much stronger martensitic condition, which is further strengthened by strain hardening and aging. The bottle measures about 3 inches in diameter by 10 inches overall length and weighs a little more than one pound. It can withstand a working pressure of 2,000 lbs. and, when filled to capacity, contains about 120 litres of oxygen, enough to support a man for about two hours.

Quite extensive testing was done on one of the bottles by the General Equipment and Packaging Laboratory at Natick Laboratories (6). Testing included pressurized tests at both high and low temperatures, test on the effect of thermal shock, salt spray, vibration, and a destructive test involving an impact with a high-velocity projectile while in the pressurized condition.

A two-stage regulator, built by the Scott Aviation Corporation under contract to the NCTRU, is used to feed the oxygen into the suit at the rate of approximately one litre per minute.

This alternate, oxygen-supply system, developed concurrently with the chemical, oxygen-producing system, was to be used only if the chemical approach proved to be unsatisfactory. Because the chemical system was highly satisfactory, however, no provision for the high-pressure oxygen system will be made in future models of the ECU.

After passing through the chemical pack, the air is drawn into the plenum and exhausted through the outlet into the suit helmet. An electrically driven blower, made by the Torrington Company, circulates air. Driven by a 12-volt Globe DC motor running at about 12,000 RPM, this centrifugal-type blower is designed to produce an air flow of 27 cubic feet per minute against a pressure head of three inches of water. Testing at NCTRU has shown that it will meet that requirement, drawing 2.65 amperes at 12 volts.

The performance of the blower is shown graphically in Figures 5A and 5B where static head, current consumption of RPM are plotted against airflow for three voltage levels--8, 10 and 12 volts. The blower exhausts into a GP2 sound-foam-lined plenum, and from there, directly into the helmet. The noise level within the helmet, from the fan, is about 70 db.

Power is obtained for the ECU from a 12-volt, 10-ampere-hour, silver-zinc battery (Silvercell) made by the Yardney Company. The battery, which provides ample power for a two-hour run, weighs only five pounds, including the case, which is attached externally to the ECU with quick-release fasteners. The silver-zinc battery requires eight cells for a 12-volt output. Each cell contains a small quantity of an alkaline electrolyte (potassium hydroxide) which is largely absorbed by the plates and separators, resulting in an almost unspillable battery. Charging may be accomplished by an inexpensive, modified, constant potential charger requiring approximately 24 hours for a full charge from the fully discharged condition. The life expectancy of the silver-zinc battery after activation is claimed to be 1 to 1-1/2 years by the manufacturer, depending on maintenance and storage conditions. The cycle life is claimed to be 80 to 100 cycles. (Tests conducted at NCTRU on a set of eight silver-zinc cells that had been stored for approximately one year under rather adverse conditions ran for 40 test cycles over a period of 6 to 7 months before failure occurred.)

Additional tests were run on a battery composed of 12 silver-cadmium cells, made by the same manufacturer. Although these cells produce only about 2/3 of the voltage of the silver-zinc cells, they have a much longer life expectancy, that is, over three years under optimum conditions. Indeed, under optimum conditions, the cycle life of the silver-cadmium batteries seems almost unlimited for practical purposes. For example, Silcad batteries under vacuum conditions have withstood over 7,000 shallow charge-discharge cycles. In continuing tests at NCTRU, the Silcad batteries have withstood 130 deep charge-discharge cycles. These cells were activated about 40 months ago and show no sign of deterioration to date, such as loss of capacity or sediment accumulation in the bottom of the cells.

A highly functional innovation, from a safety standpoint, is the oxygen-sensing warning device shown attached to the backpack in Figure 6. This instrument, which was developed by the Beckman Instrument Company, Inc., under contract to NCTRU, monitors oxygen from a polarographic sensor mounted in the plenum and warns the wearer by a red light whenever the oxygen level falls below or rises above safe values. The unit draws very little current (the maximum is about 125 ma). Tests have shown that it responds very quickly to changes in oxygen partial pressure, is essentially insensitive to change in temperature and relative humidity, and is a highly reliable and apparently nearly maintenance-free device. The entire unit weighs approximately one pound. A technical report describes this instrument in detail and presents the results of the testing done by NCTRU (7).

A low-profile, communications headset compatible with existing sound-powered Navy gear has been developed by Dyna-Magnetic Devices, Inc., under contract to NCTRU, for use with the DCS. The headset uses a bone-conduction-type microphone mounted at the rear of the head. All of the electronics required for this system are contained within the headset, which weighs approximately one pound (8).

TESTING

Exhaustive tests have been conducted on the backpack to determine airflow rates, cooling rates and the cooling capacity of the freeze canisters. These tests were held in an environmentally controlled chamber with the use of an "open circuit" configuration; that is, inlet air was drawn from, but exhausted outside of, the chamber. The outlet air was not allowed to return to the backpack as it does when the backpack is used with the DCS. Testing in this manner allowed accurate control over both inlet temperature and relative humidity. Airflow was measured directly with a hot-wire air-velocity meter (Flowtronic model 55A1). A sensor was mounted in a special flow tube, made and calibrated by Flow Corp., to read directly in cubic feet per minute. Exhaust air from the backpack was passed through the flow tube and the flow rate continually monitored. Electrical power for these tests was supplied by a filtered, adjustable, DC-power supply.

Temperature and relative humidity measurements were made with wet and dry thermocouples. Some difficulty was experienced by the drying out of the wet couples; however, in most tests the humidity was high enough to prevent this from happening during the test periods. Signals from the thermocouples were recorded on a multipoint, Honeywell temperature recorder.

The rate of water extraction, airflow, and temperature difference between incoming and outgoing air were used to calculate the rate of heat absorption by the backpack. Since heat absorption rates were generally decreasing and data were taken at the end of every 15-minute period, conservative values were obtained.

During testing the ECU was mounted on a sensitive scale which could be read to the nearest 1/4-ounce. At the end of every 15-minute period the increase in the weight of the ECU, due to the condensed water, was noted and recorded for use in calculating the heat absorbed by the freezepack.

Manometers were connected to the ECU at various points of interest so that the pressure drops through the ECU could be measured. Typically, the output of the fan, for a 12-volt motor input, was 30 to 34 cubic feet per minute at a pressure head of 2 to 2-1/2 inches of water. The pressure loss between the inlet and the outlet of the freeze packs was typically 0.2 inch of water.

RESULTS AND DISCUSSION

Water vs Sodium Thiosulphate Solution

The finned, aluminum canisters used for holding the refrigerant solutions were supplied by the manufacturer filled with six pounds of a solution reported to be water with 10-percent sodium thiosulphate and six-percent alcohol added. The use of this frozen salt solution instead of plain ice for cooling purposes had been advocated to take advantage of the negative heat of solution found in some salts and to lower temperature of the melting ice and thereby enhance the transfer rate of heat from the air to the canister fins.

Tests were run using both the salt-alcohol-water solution and plain water frozen in the canisters to determine the relative performance of both liquids. The initial tests were conducted on the backpack, with the cooling canisters in place, in a room at 90°F and 65 percent RH. Inlet air was drawn directly into the backpack from the chamber while exhausted air was passed through an instrumented flow tube used for measuring the flow rate.

Results from the tests using the solution-filled canisters show a very high initial rate of heat absorption but, after about one hour, the rate of heat absorption fell to an unacceptably low level though ice remained in the canisters (Figure 7). In the tests run with plain-water-filled canisters, on the other hand, the rate of heat absorption, after an initial drop during the first half hour or so, typically increased during the next half hour and thereafter maintained a relatively high level until all of the ice was melted. In these tests the total BTU outputs from the water-and-solution-filled canisters (as estimated from the curves in Figure 7) did not appear to be materially different. Thus, from a performance point of view, plain ice appeared to be the better choice.

The initial high rate of heat absorption for both the water-and-solution-filled canisters occurs before the super-cooled ice starts to melt. Once melting begins, the insulation afforded by the layer of water between the ice and the can retards the heat flow. Apparently, once this layer becomes thick enough, convection currents form which increase the rate of heat transfer--hence the recovery noted in the rate of heat absorption in all of the tests using plain ice. Melting of the frozen, sodium-thiosulphate solution, on the other hand, results in the formation of a viscous slush which presumably inhibits convection. Consequently, the rate of heat transfer continues to decline.

Additional experiments were conducted to investigate further the low rate of heat absorption noted for the solution-filled canisters. A cylindrical aluminum can containing four pounds of the sodium-thiosulphate, alcohol solution was placed in an insulated calorimeter containing 31 pounds of water at ambient temperature. Provision was made for continually agitating the water and recording its temperature. The experiment was duplicated using plain-water ice in the can and the results (illustrated in Figure 8, in which rate of heat loss is plotted against time) confirm the previous findings that heat is more readily absorbed in plain ice than in ice made from the sodium-thiosulphate solution. Furthermore, measurements made in a vacuum-insulated calorimeter, where ice was melted directly in water, showed that plain-water ice absorbs about five-percent more heat in melting than ice made from the solution. Thus, since plain-water ice appeared to be an all-around better performer than the sodium-thiosulphate solution, it was used exclusively for the remainder of the tests.

Effect of Variables on Rate of Heat Extraction

In general, tests were conducted at the relatively high temperatures and humidity levels expected to occur at the outlet of an impermeable suit containing a working man. Test temperatures ranged from 80° to 100°F and relative humidities from 80 percent to nearly 100 percent. Three rates of airflow through the pack were used, that is, 15, 22, and 35 cfm.

Effect of Temperature and RH. The effect of inlet air temperature on the rate of heat absorption is illustrated in Figure 9. Relative humidity was held at 80 percent for these tests and each data point represents the average of two, and in some cases three, tests. The airflow rate was 35 cfm.

Note that, in general, heat-absorption rates are well above the 1000 BTU level which is considered to be the practical minimum required for comfort at the activity levels of interest. While temperature has a very significant effect on the total rate of heat absorption, its effect on sensible heat extraction (lower set of curves) is almost insignificant. This apparent anomaly stems from the higher rate of water condensation resulting from the greater moisture content of the warmer air.

The effect of relative humidity on heat extraction is shown in Figure 10 for an airflow of 21 cfm and a temperature of 95°F. The effect on the rate of heat extraction of the humidity change from 85 percent to 95 percent is quite small. It is the result of a change of about 12 percent in the absolute water content of the air. Compare this effect with that in the previous illustration where a change of almost 60 percent in absolute water content resulted from the temperature change from 85 to 100°F at constant RH.

Effect of Rate of Airflow. Figure 11 illustrates the effect of the rate of airflow through the backpack on the rate at which heat is extracted. The effect, although apparently quite small between 22 and 35 cfm, is to reduce the rate of heat extraction very significantly at 15 cfm.

Figures 12 and 13 show the performance of the chemical pack (breathing canister) under conditions using a "simulated man" to absorb oxygen and expel carbon dioxide and water vapor (5). These data demonstrate that, under the conditions of test, the breathing canisters were able to maintain the ambient-oxygen level and to hold the carbon-dioxide level below 0.4 percent.

Test of the ECU-DCS System

Some tests were run with the ECU attached to a manikin placed inside the DSC. These tests were held to determine airflow rates within the suit itself and to determine environmental heat loads on the ECU for different wind velocities. Figure 14 illustrates the effect of wind velocity on the rate at which heat was absorbed through the suit. This heat, and the heat emanating from the wearer's body and from the chemical pack, must be extracted by the ECU. Note that, at the test temperature of 120°F in a wind of approximately 1500 ft/min (about 17 mph), approximately 900 BTU/hr was required to balance t e heat being conducted through the walls of the suit. During this test, the air temperature at the ECU outlet was in the 70° to 75°F range.

In Table I, the effect of external temperature on the heat absorbed through the suit is presented. It should be noted, however, that since these tests were run with the use of a manikin inside the suit the internal temperatures were much lower than would have been the case had the suit been manned by a live subject. As a result, the values of heat absorbed are presumably unrealistically high. For instance, at a 72°F external temperature, 230 BTU/hr were absorbed. If the suit had been manned, the internal temperature would have been greater than 72°F and the net heat flow would have been in the opposite direction, resulting in a heat loss instead of a gain. The internal temperature of the suit for this test averaged about 60°F.

Table I. Effect of temperature on heat absorption through DCS.
(with dummy in suit and a 120-fpm wind velocity)

External Temperature °F	Heat absorbed by suit BTU/hr (average for 120 mins.)
140	800
120	550
75	230

Manned Tests

Physiological testing of the entire system in ambient temperatures of 70, 100, and 140°F has been completed and the data are currently being evaluated. A separate report covering this phase of the testing will be written.

During these tests, temperature, oxygen, and carbon dioxide levels were monitored continuously. During the tests, temperatures within the suit ranged from 70 to 80°F at the 70°F ambient at the outlet of the ECU. The 80 to 100°F ambient and 80 to 110°F ambient at the 140°F ambient associated with the higher suit temperatures were very low. Thus metabolic heat could be dissipated by evaporation even at the high suit temperatures.

The chemical pack was very satisfactory as a source of the O_2 and as an absorbent of CO_2. Oxygen levels within the suit were typically within $\pm$ 2.0 percent of the ambient level; however, in one instance, the oxygen level did drop to about 4.5 percent below normal. Carbon-dioxide levels were generally maintained in the vicinity of 0.2 percent except toward the end of each test when the levels rose to about 0.6 percent. The maximum level for carbon dioxide observed in any of the tests was 1.3 percent.

These tests showed that the system can support a man for one hour at 140°F performing light activity, for at least two hours of light activity up to 100°F, and for one hour of moderate to heavy activity at 100°F or less. The chemical pack, however, was a greater heat burden on the cooler capacity than had been anticipated from man-simulator tests. It now appears that more refrigerant fluid will be needed to balance this additional heat load for the temperature duration activity levels mentioned previously.

CONCLUSION

The objective of this work was to develop an environmental control unit capable of supporting a man in an impermeable suit at ambient temperatures up to 140°F for periods up to two hours. The results indicate that the two-hour duration at high temperature has not been met (two hours is possible up to 100°F). At the high temperature (140°), cooling is sufficent for about 60 minutes. Oxygen production and carbon-dioxide scrubbing appear to be adequate. The oxygen-sensing warning device works very well and adds a new safety dimension to the system.

Modifications contemplated for the ECU, when funding is available, should make the suit more comfortable to wear and much more practical for use in the confined spaces found aboard ship. For instance, the ECU, now worn on the back, can be styled in a torso configuration to facilitate entry through the small hatches and passageways aboard ship.

APPENDIX A. ILLUSTRATIONS

-11-

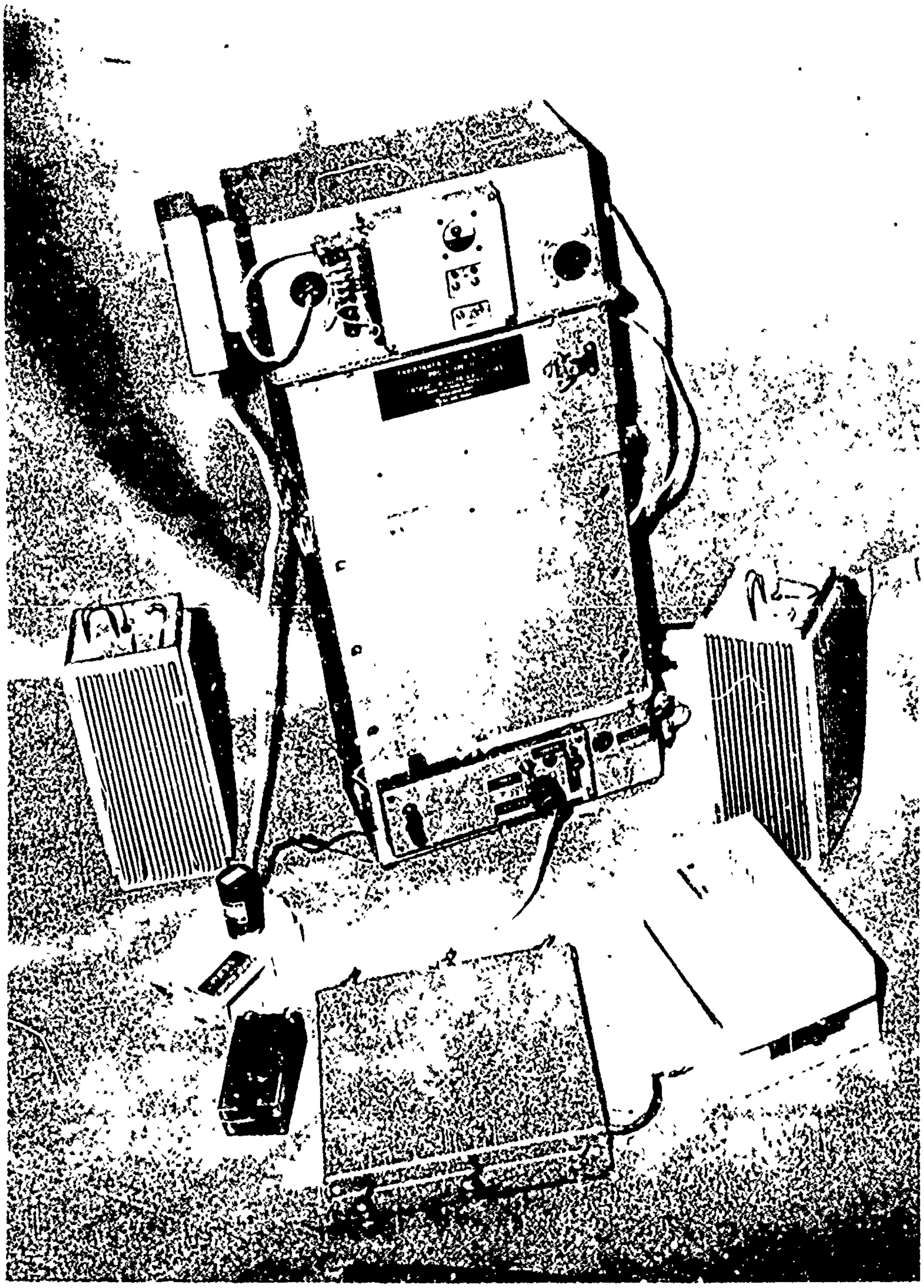

Figure 1. Environmental Control Unit Backpack and Component Parts.

Figure 2. Side View of Model II Prototype Damage Control Suit.

Figure [illegible]. Support Frame for ECU.

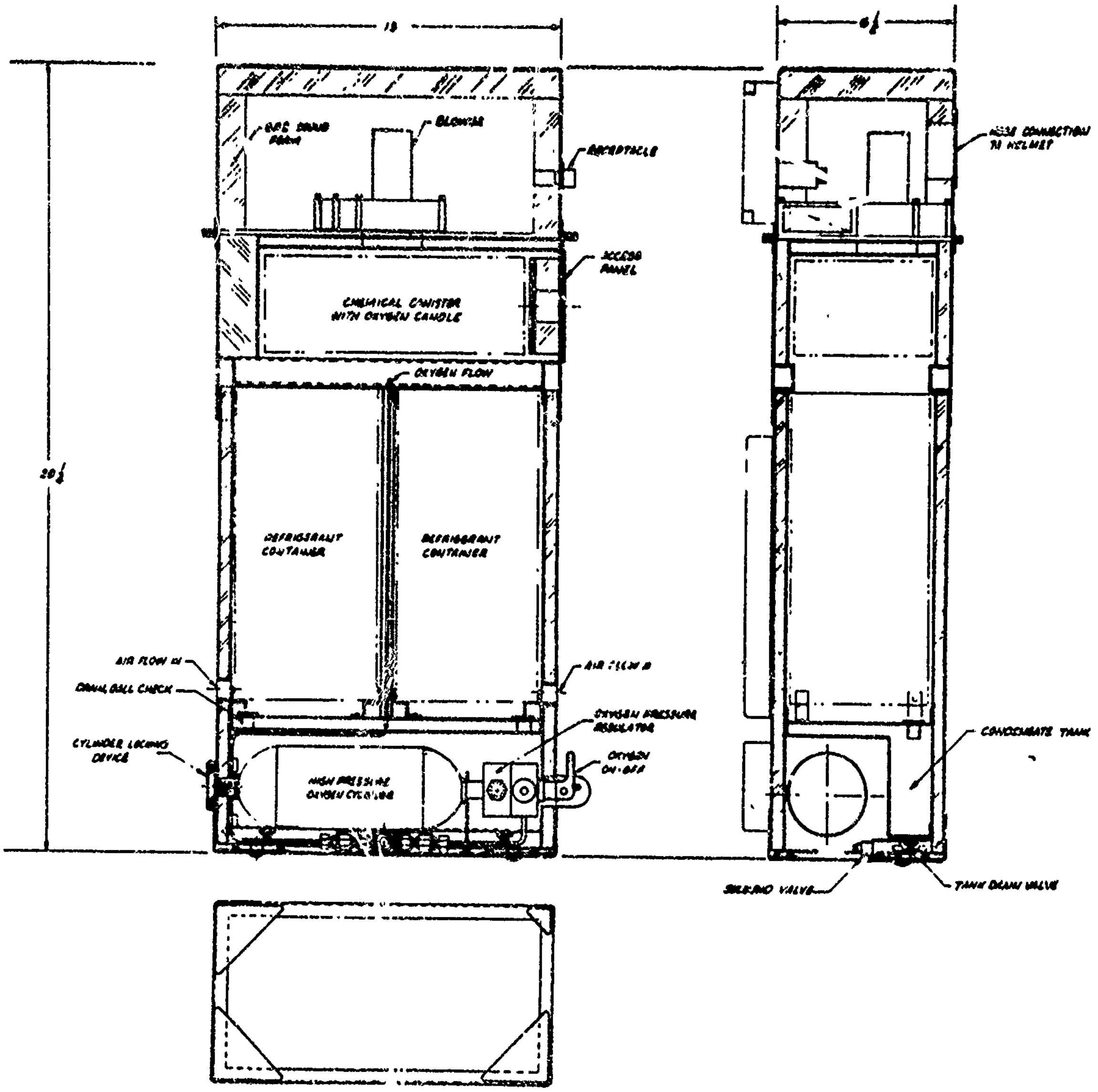

Figure 4. Environmental Control Unit Schematic.

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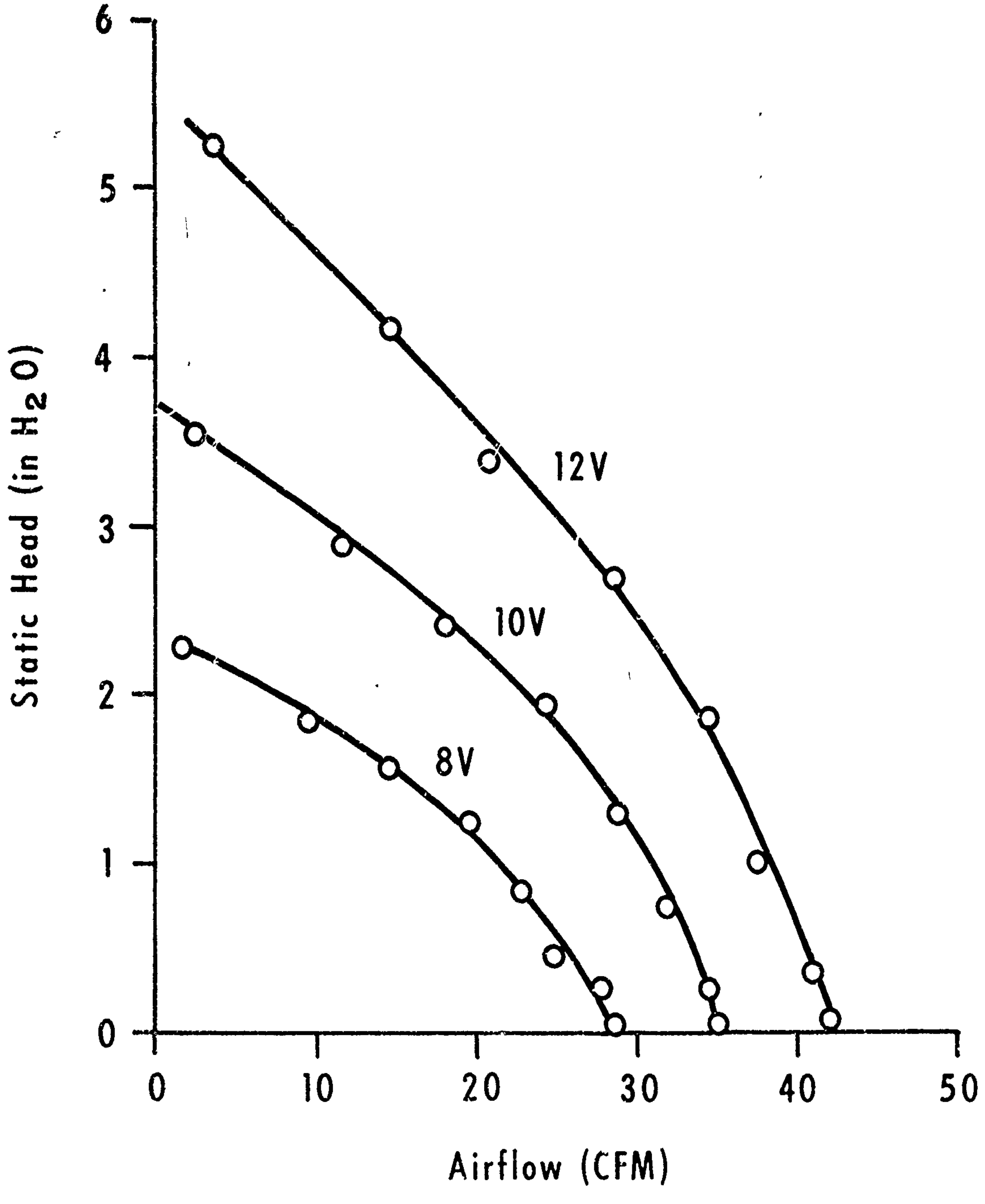

FIGURE 5A. PERFORMANCE OF TORRINGTON BLOWER: STATIC HEAD vs AIRFLOW for 12, 10 and 8 VOLTS.

-16-

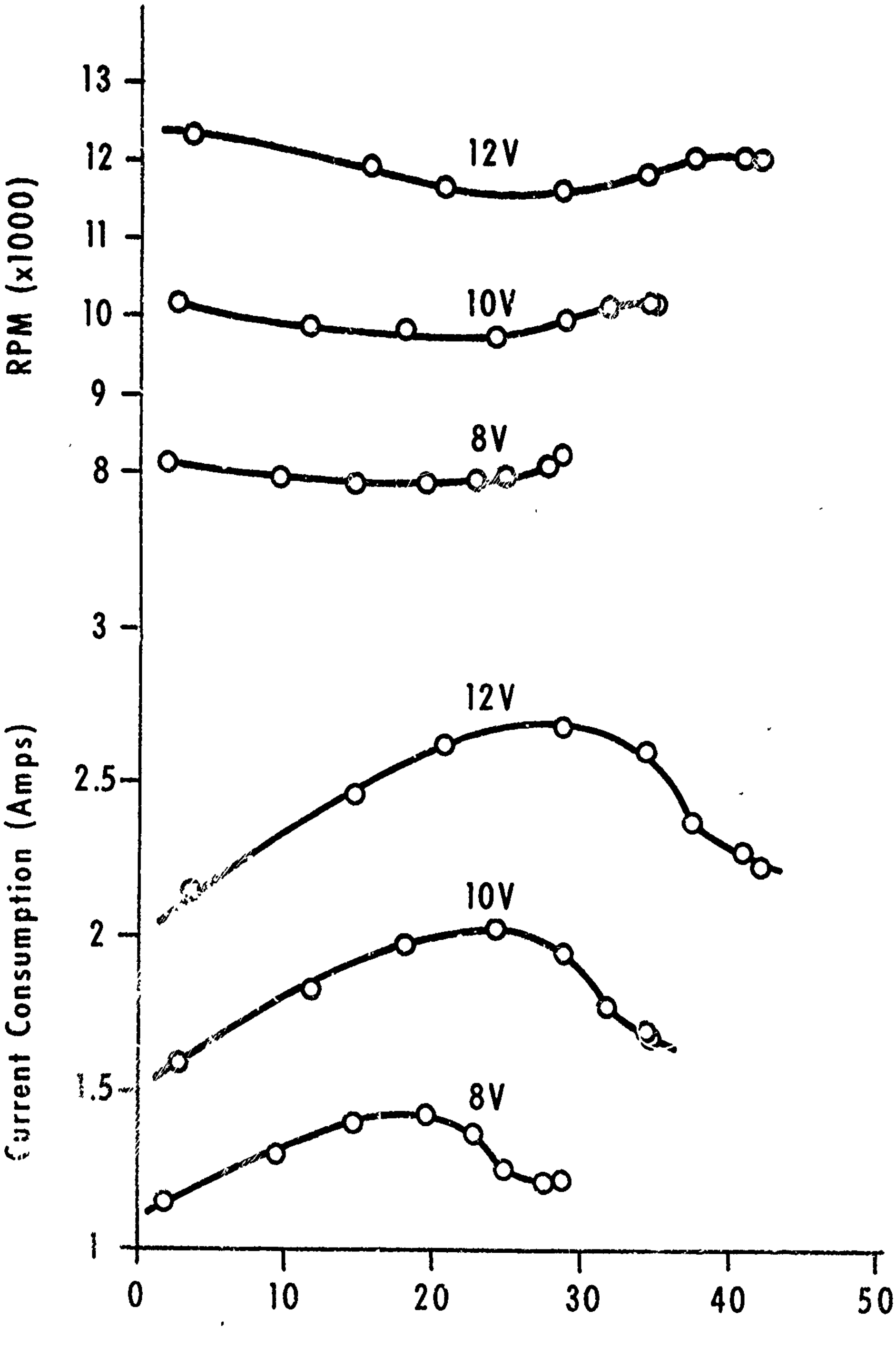

FIGURE 5B. PERFORMANCE OF TORRINGTON BLOWER: CURRENT CONSUMPTION and RPM vs AIRFLOW for 12, 10 and 8 VOLTS.

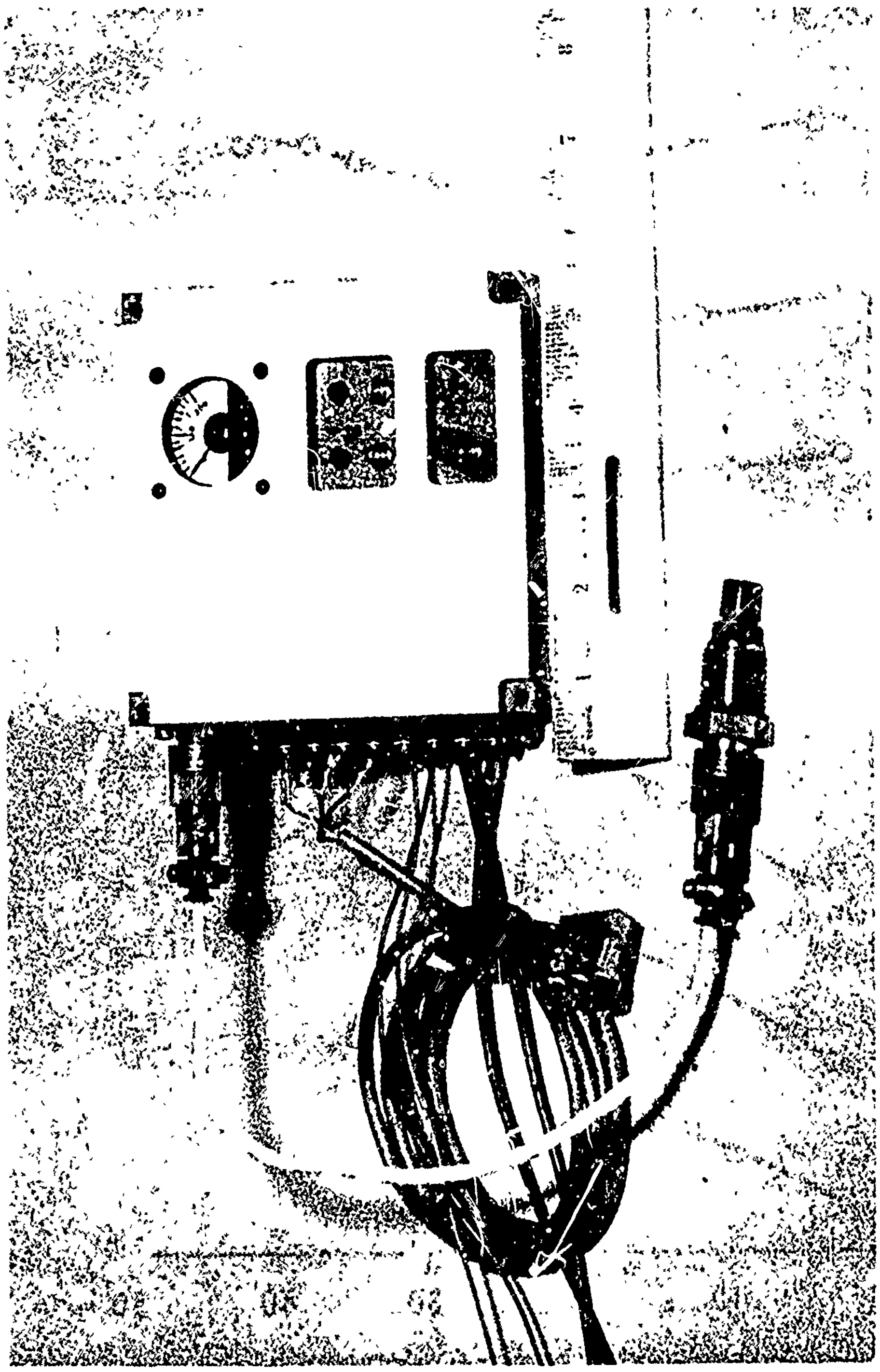

Figure 6. Oxygen-Sensing Warning Device.

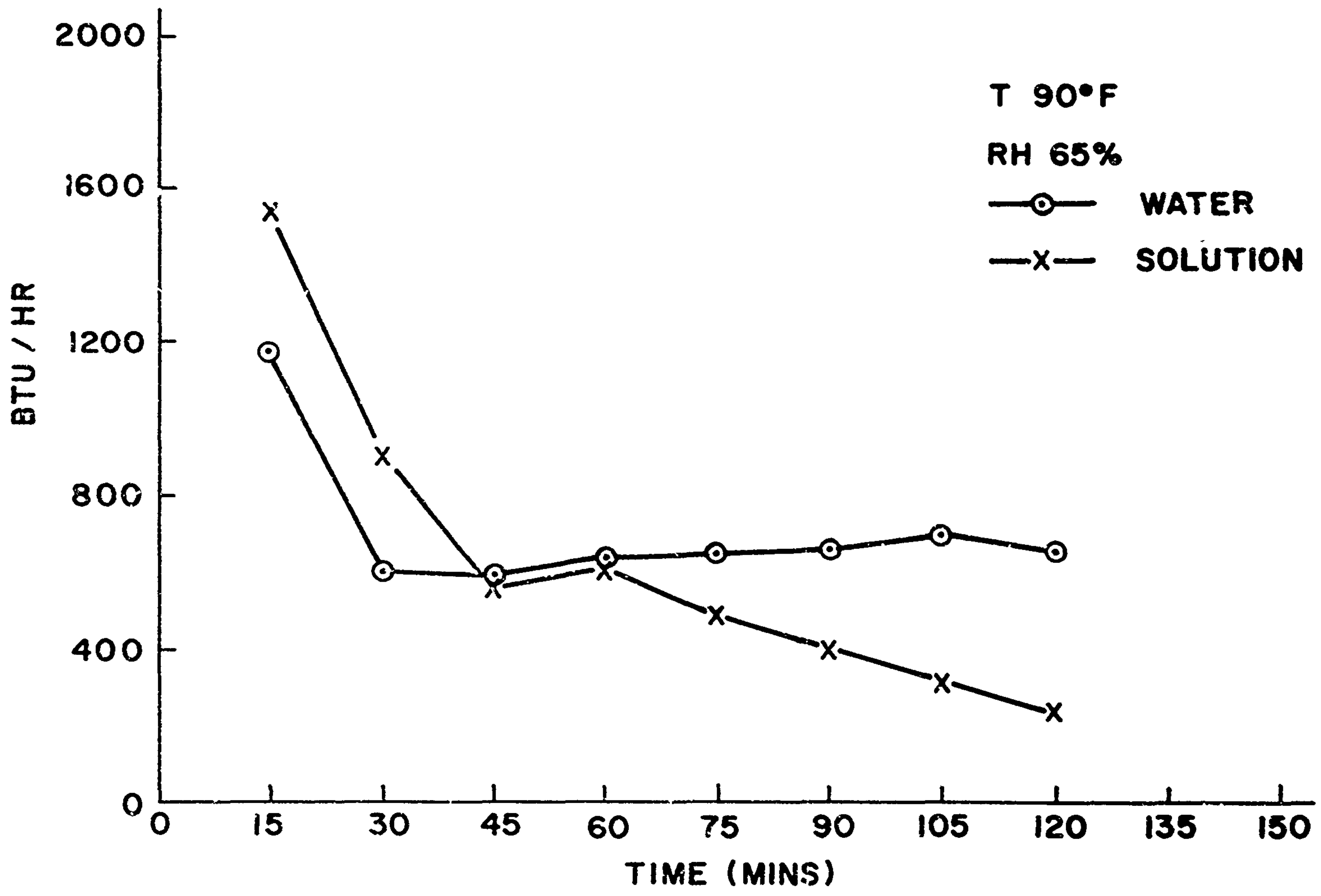

Figure 7. Comparison of Heat Absorption Rates vs Time for Water and for Sodium-Thiosulphate-Alcohol Solution in Canisters.

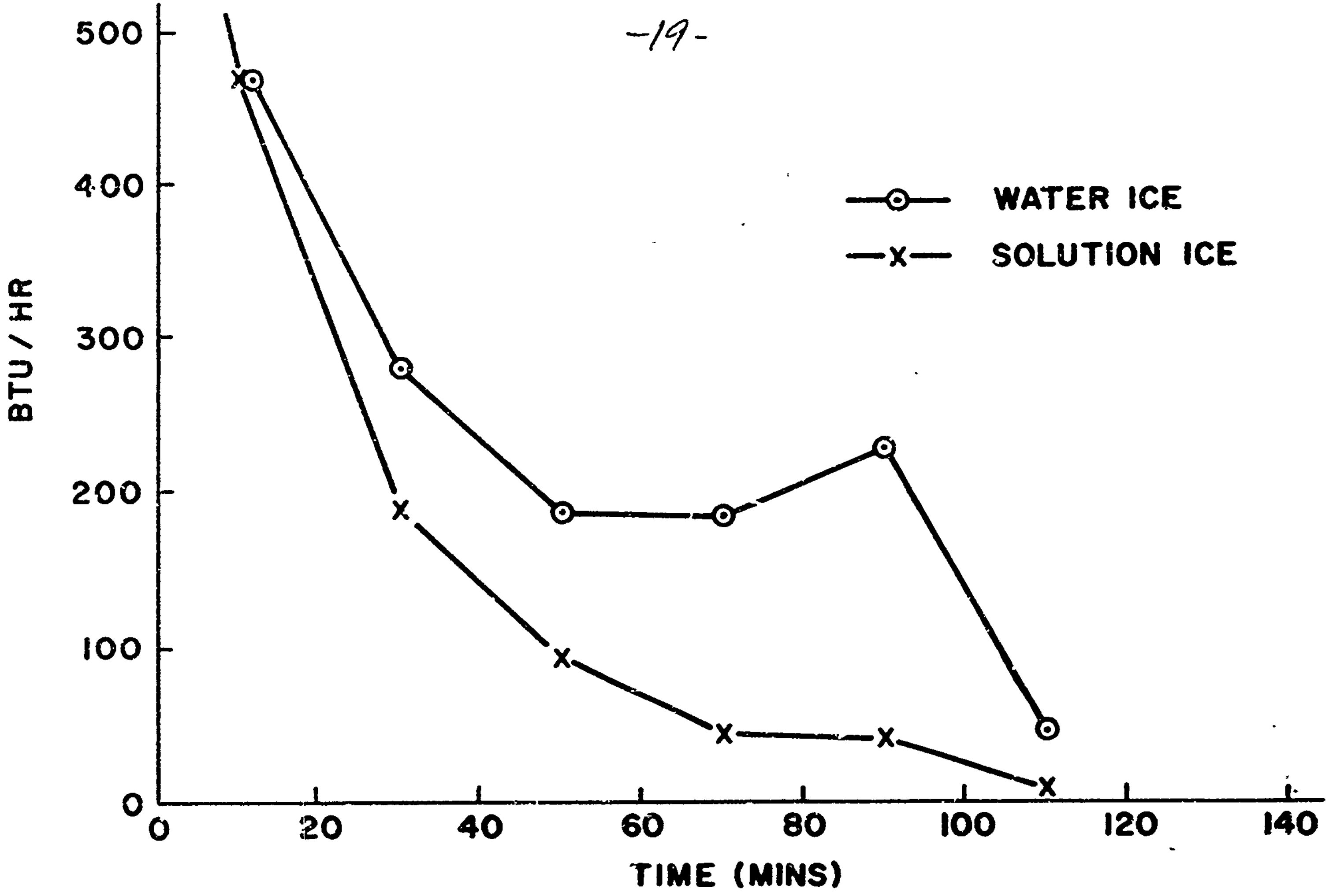

Figure 8. Comparison of Heat Absorption Rates vs Time for Water and for Sodium-Thiosulphate-Alcohol Solution in a Calcrimeter.

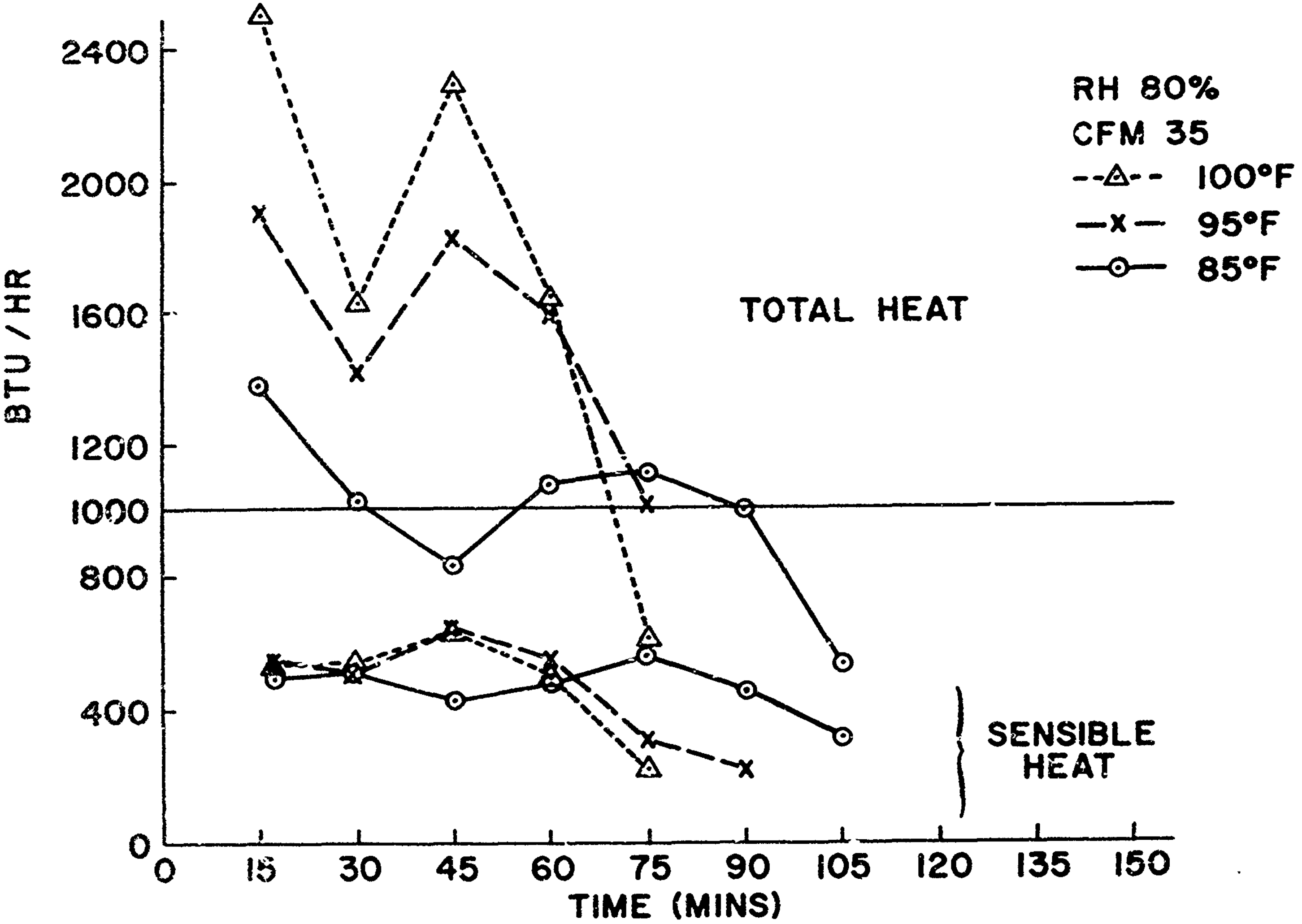

Figure 9. Effect of Inlet Air Temperature on Heat Absorption Rates of Canisters in ECU.

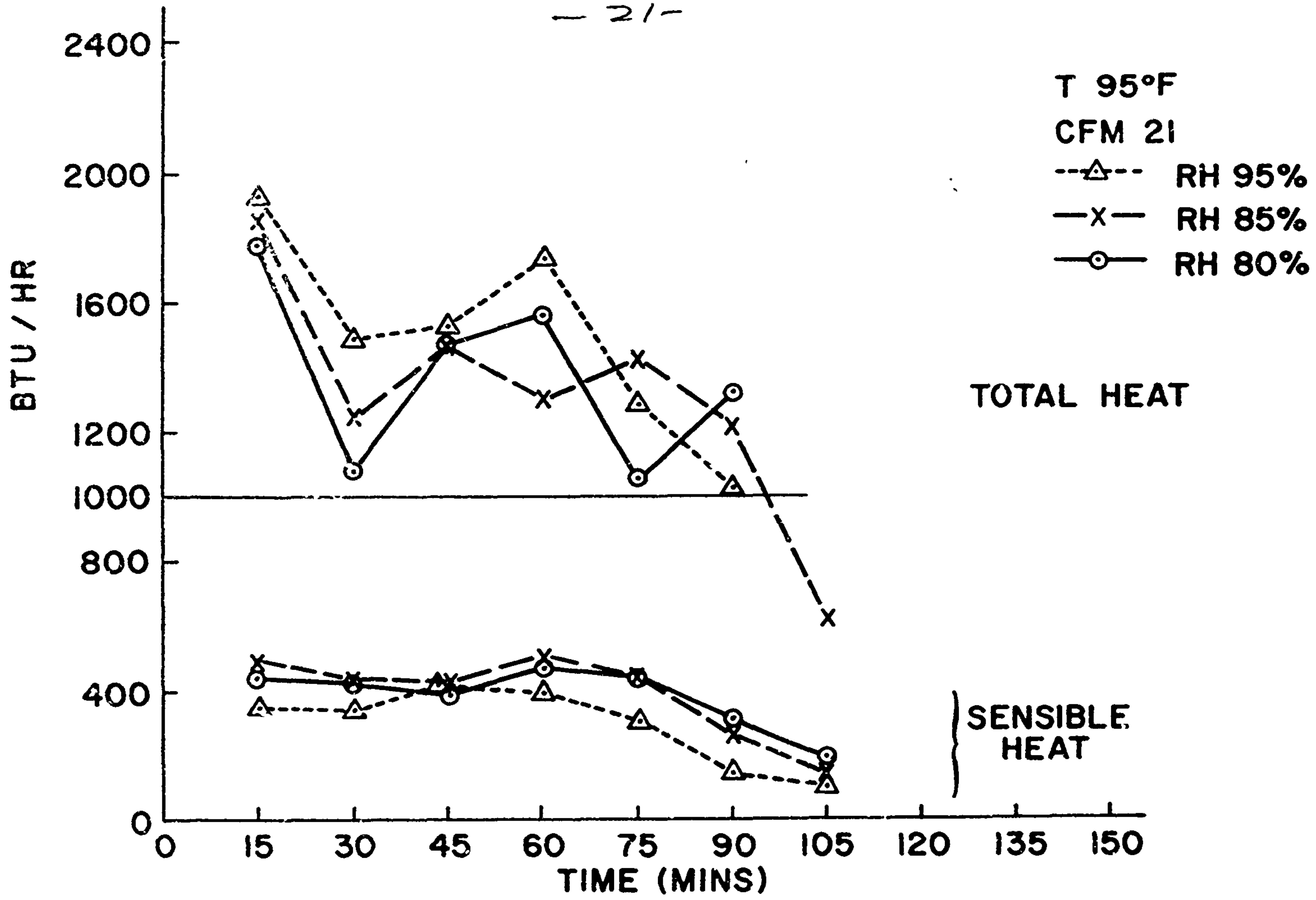

Figure 10. Effect of Relative Humidity of Inlet Air on Heat Absorption Rates of Canisters in ECU.

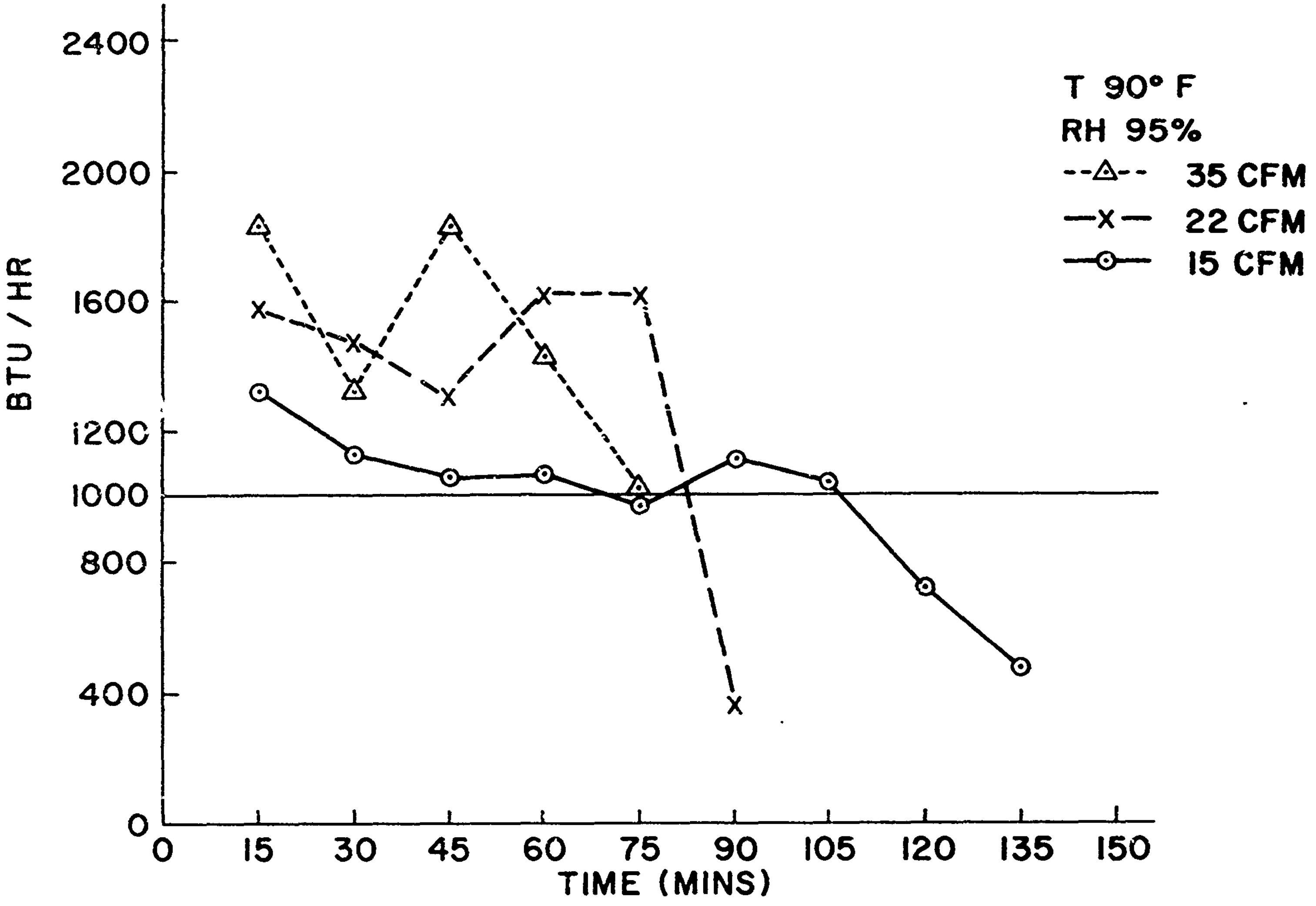

Figure 11. Effect of Rate of Airflow Through ECU on Heat Absorption Rate.

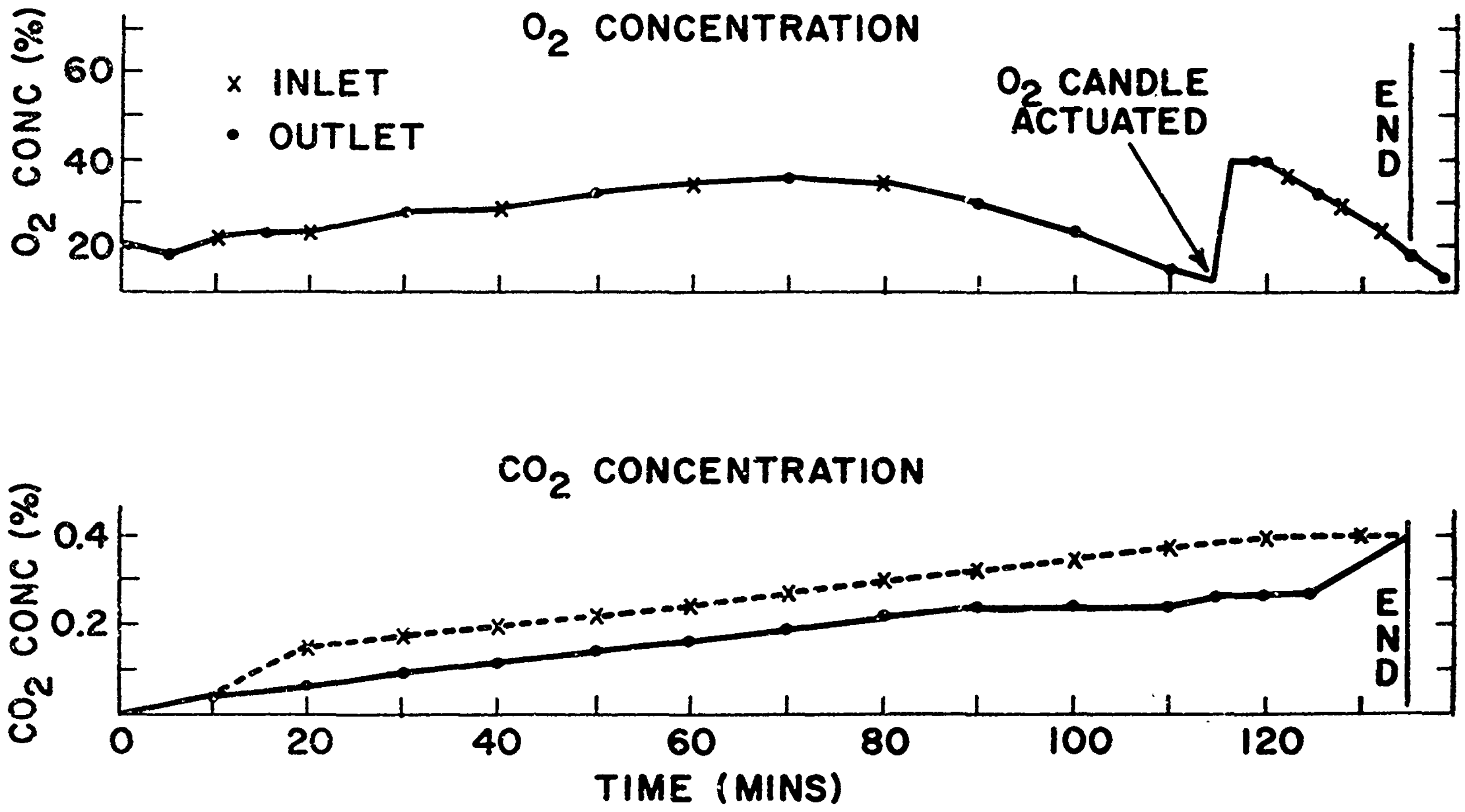

Figure 12. Performance of Chemical Breathing Canister.

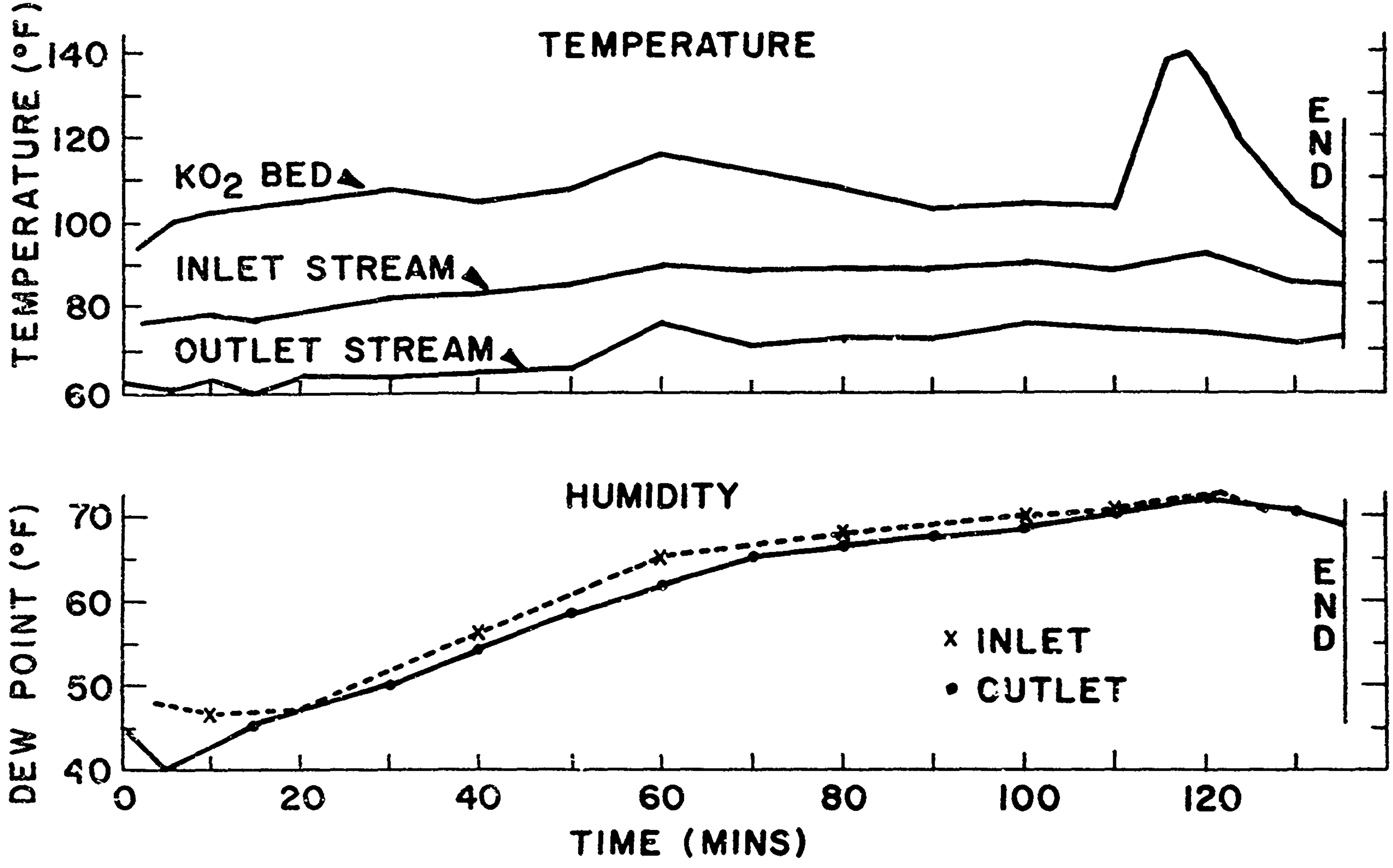

Figure 13. Temperature Characteristics of Chemical Breathing Canister.

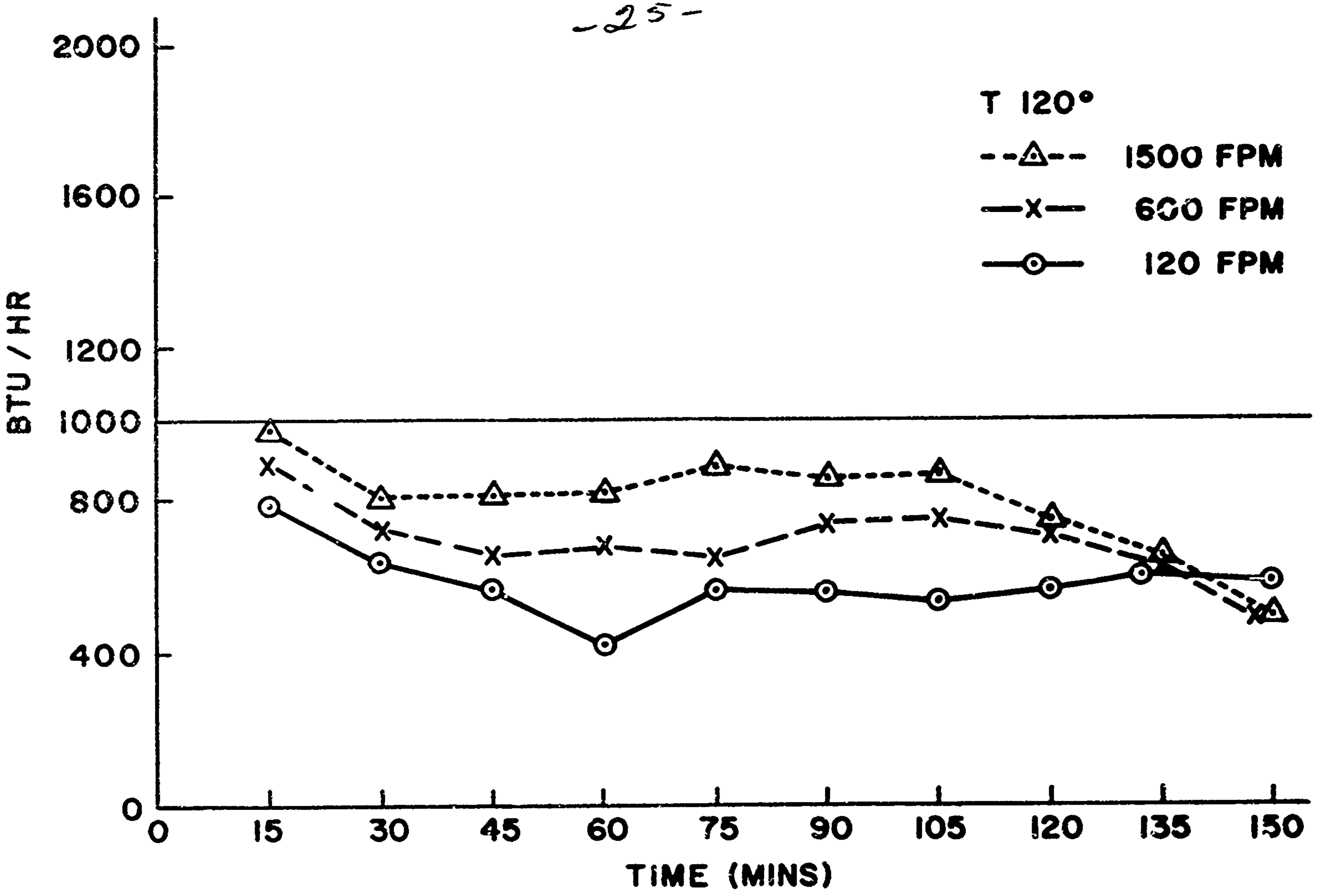

Figure 14. Effect of Wind Velocity Over Damage Control Suit on Heat Absorbed with Dummy in Suit.

Appendix B. References

1. D'Amico, S., et al., "Development of an Air Circulating Unit for Ventilation of Impermeable Suits," U.S. Naval Supply Activities, New York Clothing Supply Office, Brooklyn, New York, July 1955.

2. Lash, S. and D'Amico, S., "Development and Evaluation of a Machinery Spaces Air-Supplied Suit," U.S. Naval Supply Research & Development Facility, Bayonne, New Jersey, C & T Report No. 41, November 1959.

3. McLoughlin, R., "Evaluation of a Thermoelectric Suit for Cooling Capacity," U.S. Naval Supply Research & Development Facility, Bayonne, New Jersey, Informal Technical Report No. 24-12/61, December 1965.

4. Weiss, R.S., "Physiological Evaluation of a Liquid Air Protective Suit," U.S. Naval Supply Research & Development Facility, Bayonne, New Jersey, NO. RENS 80-02-002-00-01, November 1965.

5. King, J.C. and McGoff, M.J., "Development of Chemical Breathing Canisters for a Closed-System Maskless-Suit Application," MSA Research Corporation Report No. MSAR 70-30, under NCTRU Contract No. N00289-69-CB 054, July 1970.

6. NLABS Report "Environmental Testing of High Pressure Oxygen Bottle," Ref. AMXRE-GE 26 January 1971.

7. Audet, N.F. and Orner, G.M., "Development and Evaluation of Oxygen Sensing and Warning Device," NCTRU Technical Report No. 98, December 1971.

8. Audet, N.F., Chadwick, A. H., and Hofer, A., "Development and Evaluation of Inertial Microphone Headset System," NCTRU Technical Report No. 100, June 1972.